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Epixylic lichens and bryophytes in young managed forests

-substrate preferences and amounts of dead wood

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Abstract
Dead wood is important for many species. The amount of coarse dead wood (diameter >10 cm) is much lower in managed forest than in unmanaged forests. Stumps constitute the largest proportion of the volume of coarse dead wood in managed forests. Since stump harvest for biofuel may increase, the amount of dead wood will decrease even more, which may threaten biodiversity. The first aim of this study was to compare the amounts of fine woody debris (FWD, <10 cm in diameter) and coarse woody debris (CWD), in young managed forest stands. The second aim was to investigate if epixylic lichen and bryophyte occurrences were affected by substrate qualities. In seven stands (9-16 years old) in the province of Uppland I estimated the amounts of dead wood, and recorded substrate quality variables and occurrence of eight lichen and five bryophyte species. Number of objects and surface area were larger for FWD than CWD, while the volume was higher for CWD. Five of the 13 focal species were found, among which the occurrence probabilities of the lichens *Cladonia botrytes*, *Xylographa parallela* and *Mycocalicium subtile* could be analyzed statistically. *C. botrytes* only occurred on CWD, and there was a higher probability of occurrence on stumps than on logs. The occurrence probability of *X. parallela* was higher on CWD than on FWD. For *M. subtile* the probability of occurrence was not affected by substrate variables. Stumps are important substrates for *C. botrytes,* which is an argument against stump harvest. If choosing between harvesting slash (i.e. branches and tops) or stumps, this study suggests that stump harvest gives the most negative effects on occurrence probabilities in young managed forest stands of two epixylic lichens. However, more perspectives have to be included to be able to in full evaluate stump harvest.

Key words: Stump harvest, fine woody debris, coarse woody debris, species occurrence.

Sammanfattning
Död ved är viktigt för många arter. I brukade skogar är mängden grov död ved (diameter >10 cm) mycket lägre än i obrukade skogar. Stubbar utgör den största andelen av den grova döda vedens volym i brukade skogar. Eftersom stubbskörd kan komma att öka kommer mängden död ved sjunka ännu mer, vilket kan hota den biologiska mångfalden. Det första syftet med denna studie var att jämföra mängden klen död ved (FWD, <10 cm i diameter) och grov död ved (CWD) i brukade ungskogar. Det andra syftet var att undersöka om vedlevande lavars och mossors förekomst påverkades av olika substratkvaliteter. I sju bestånd (9-16 år gamla) i Uppland uppskattade jag mängden död ved och registrerade variabler över substratkvaliteter samt förekomst av 8 lavarter och 5 mossarter. Antal dövedsobjekt och ytarea var större för FWD än CWD, medan volymen var högre för CWD. Fem av de 13 studiearterna hittades, varav *Cladonia botrytes*, *Xylographa parallela* och *Mycocalicium subtile* kunde analyseras statistiskt. *C. botrytes* förekom endast på CWD och det var större sannolikhet för förekomst på stubbar än på lågor. Sannolikheten för förekomst av *X. parallela* var högre för CWD än FWD. För *M. subtile* påverkade ingen registrerad variabel sannolikheten för förekomst. Stubbar är viktiga substrat för *C. botrytes*, vilket är ett argument mot stubbskörd. Om valet står mellan att skörda grot (d.v.s. grenar och toppar) eller stubbar ger enligt denna studie stubbskörd de mest negativa effekterna på sannolikheten för förekomst av två vedlevande lavar i brukade ungskogar. Emellertid måste fler perspektiv tas hänsyn till för att kunna utvärdera stubbskörd fullständigt.

Nyckelord: Stubbskörd, klen död ved, grov död ved, artförekomst.

Populärvetenskaplig sammanfattning

Död ved, till exempel grenar och toppar som lämnats vid avverkning, stubbar samt liggande och stående döda träd, är viktigt för många arter. Brukade skogar innehåller mindre mängder grov död ved än obrukade. Det har lett till att många arter som är beroende av död ved är sällsynta i dessa miljöer. Mängden död ved kan minska än mer genom skörd av stubbar för t.ex. biobränsle. Det är viktigt att ta reda på vilka typer av död ved som används av vedlevande organismer samt vilka andra egenskaper hos den döda veden som kan påverka arterna. Resultatet skulle kunna användas som en del av utvärdering av stubbskörd och annan skörd av ved. Ett av syftena med undersökningen var att uppskatta mängden död ved i brukade ungskogar och beskriva hur stor andel av veden som utgörs av klen respektive grov död ved. Jag ville också undersöka om förekomsten av vedlevande lavar och mossor påverkades av olika egenskaper hos den döda veden samt av andra faktorer som t.ex. graden av solinstrålning på veden. Jag letade efter sammanlagt 13 lav- och mossarter som i stort sett endast förekommer på död ved. Vissa av dessa är vanliga medan andra är ovanliga.

I studien jämfördes mängden klen död ved och grov död ved på tre olika sätt. För det första var det fler bitar klen än grov död ved per hektar. För det andra var den döda vedens sammanlagda yta per hektar större för klen än för grov död ved. För det tredje var den sammanlagda volymen död ved per hektar större för grov än för klen död ved. Varje bit klen död ved har per definition mindre diameter och kan därmed ha mindre volym än grov död ved. Detta leder till att volymen grov död ved kan vara större än volymen klen död ved, samtidigt som antalet bitar är större för klen död ved.

Fem arter av de tretton lavarna och mossorna observerades i undersökningen: svart spiklav, stubblav, småspik, strecklav och vedblekmossa. Stubblav, strecklav och småspik förekom i så stor mängd att de kunde analyseras statistiskt. Stubblav fanns endast på grov död ved, oftare på stubbar än på liggande döda träd. Strecklav förekom oftare på grov död ved än på klen död ved. Att vissa vedlevande lavar finns i större omfattning på grov död ved kan bero på den större ytan lavarna har att växa på. Dessutom tar det längre tid för grövre vedbitar att bli övervuxna av markvegetation. Fler lavarter än mossarter observerades i studien. Dessutom förekom lavarterna på fler vedbitar. Detta resultat kan förklaras med att hyggesmiljöer ofta har låg luftfuktighet och att många lavar kan klara sig med små mängder vatten, medan många mossor är beroende av ett fuktigt och stabilt klimat.

Stubbar utgör en betydelsefull del av mängden död ved och kan vara viktiga livsmiljöer för stubblav och strecklav. I andra undersökningar har man sällan inkluderat stubbar i beräkningar av mängden död ved, vilket kan tyda på en underskattning av stubbar som levnadsmiljö för arter som är beroende av död ved. Utifrån resultatet av den här studien anser jag att man bör inkludera stubbar i sådana beräkningar. Stubbar bör sparas när det är möjligt. De vanliga arterna stubblav och strecklav som idag har bland annat stubbar som livsmiljö riskerar att bli ovanliga om stubbar skördas. Fler aspekter måste dock vägas in i synen på stubbar, t.ex. förekomst och artrikedom av andra arter, skogens tillväxt och skadeorganismer på träd.

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1 Introduction
Stump harvest can decrease the amount of dead wood in the forests. The decrease may affect different organisms, such as lichens and bryophytes living on dead wood. This study is a part of a group of studies that give different perspectives of stump harvest.

1.1 Dead wood as substrate for lichens and bryophytes
Dead wood is important for sustaining high biodiversity (Samuelsson & Ingelög, 1996). More than half of the species on the Swedish Red List are connected to forests, and about half of these forest species depend on dead wood (Gärdenfors, 2005). One third of all species in the forest, red-listed or not, are dependent on dead wood. Many of the red-listed forest species have populations that are small rests of earlier larger and highly connected populations (Gärdenfors, 2005). About 200 lichen species and 70 bryophyte species in Sweden have dead wood as their main substrate (Hallingbäck, 1995; 1996).

Many epixylic (living on dead wood) lichens are small and have rapid reproduction (Spribille *et al*., 2008). This might be adaptations to their time limited substrate but it also makes them less competitive on other substrates. The supply of dead wood substrates in unmanaged stands in late decay stages is continuous; therefore species living on dead wood may only have to disperse short distances (Söderström, 1988a). In managed stands certain stages of decay may be absent, causing some species to go extinct. There are species, especially of liverworts, that are more abundant in more moist forests.

The three most important factors for a species´ preference for a forest type are: availability of substrate, microclimate and ability to disperse (Söderström, 1988a). For example in some studies it was found that humidity, shade, age of the stand, surface area and decay of the dead wood affected some species of lichens and bryophytes (Nascimbene *et al*., 2008; Caruso *et al*., 2008; Caruso & Rudolphi, 2009). Söderström (1988b) found that epixylic bryophyte occurrences on logs were affected by the dead wood´s decay class, bark cover, texture, softness, height and ground contact.

On the other hand, there are many factors that threaten the most sensitive organisms living on dead wood in Sweden (Samuelsson & Ingelög, 1996). Some important factors that threaten these species are: dead wood of the right quality is missing, uneven infusion of dead wood and long distances between substrates. Other important reasons are: the forest being too undiversified, too few fires, too few trees exposed to the sun and change in microclimate. At the clear-cut phase many species suffer from the exposure to wind and the drought of the dead wood. Partial cutting, prescribed burning and then free development in stands in the vicinity to nature reserves is suggested to be a possible way to retain the species that need dead wood in open areas, or deciduous wood in young and old stands (Siitonen, 2001).

1.2 Dead wood in unmanaged forests

An unmanaged forest is multi-layered and harbors different tree species and tree ages (Samuelsson & Ingelög, 1996). Because of the old age of many of the trees they often reach large diameters. When these trees die they form important substrates for species living on dead wood. Unmanaged forests have a great diversity of dead wood, e.g. standing (snags) and lying dead trees (logs) of different sizes.

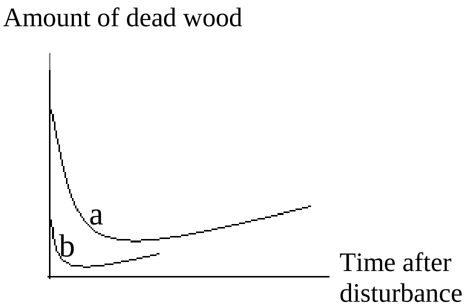

Figure 1. The volume of dead wood in time; (a) unmanaged and (b) managed stands. After Duvall (1999).

Unmanaged forests have highest volumes of dead wood directly after disturbances (Sturtevant, 1997; Clark *et al.*, 1998; Duvall & Grigal, 1999). One form of disturbance is forest fire, which affects dry and sites to a high degree, but natural fires seem to play a small role in mesic and wet sites (Syrjänen *et al.* 1994). In contrast to large gaps from forest fires, there are also smaller gaps with the origin from pathogens and windfalls, water saturation of the soil and uprooting. During the regeneration phase following a disturbance the volume of dead wood decreases, but then increases to a high volume in the old forests (Duvall & Grigal 1999) (Figure 1). The amount of dead wood in unmanaged forests reaches 90% of its maximum after 100-125 years.

1.3 Dead wood in managed forests

In the beginning of the 1900s the exploitation of the Swedish forests increased, as the demand for pulp and timber rose (Samuelsson & Ingelög, 1996). Many large diameter trees were removed. The amount of dead wood in general decreased, since it was used for example for building constructions and fuel. Other causes of the dead wood decrease were the exclusion of dead trees for preventing insect outbreaks and a decrease of old-growth forests.

In general there are higher volumes of coarse dead wood (diameter >10 cm) in unmanaged than in managed forests (e.g. Lämås & Fries, 1995; Rouvinen *et al.*, 2002). According to the Statistical Yearbook of Forestry (Swedish Forest Agency, 2009) the mean volume of coarse woody debris (CWD, diameter >10 cm) in today´s managed forests is 7.6 m^3/ha, which is about 8.6 % of the volume in unmanaged boreal forests (Linder *et al.*, 1997).

Managed forests have relatively high volumes of dead wood after logging, followed by period of decrease in the dead wood volume (Duvall & Grigal, 1999). In the end of the rotation period there is an increase in the amount of dead wood. Thus the amount of dead wood follows a U-shaped pattern in managed forests, as in unmanaged forests (Figure 1). However, the volumes in managed forests are lower and the minimum values are reached faster.

1.4 Stump harvest

The Swedish Government suggested in a proposition concerning Sweden's Environmental Objectives (2000/01:130), that the amount of hard dead wood in the whole country should increase with at least 40% to the year 2010 compared to year 1998 (Nilsson & Hellberg, 2009). The goal states that the amount of dead wood have to be enhanced even more in areas where the biodiversity is particularly threatened.

At the same time the Swedish Government has recommended stump harvest and increased harvesting of branches, tops and twigs (together called "slash") (Swedish Forest Agency, 2009). Usage of slash and stumps can lower the amounts of dead wood even further, which threatens the biodiversity in the Swedish forests (Samuelsson & Ingelög, 1996).

According to The Swedish Energy Agency (Egnell, 2007:40), stump harvest does not affect the objective that dead wood have to increase, since stumps were not included in the calculated amounts of dead wood. In Sweden stumps have been harvested before (Swedish Forest Agency, 2009). Pine stumps have been harvested for tar production until around year 1900. In the late 1970´s and during the 1980´s stumps were harvested for pulp and paper production. From 2005 stumps have been extracted for energy production. The reason is partly the transition to renewable energy sources and increasing prices for energy, which makes stump harvesting a desirable operation for Swedish forest companies.

1.5 Aim of this study

The first aim of this study is to estimate the amounts of different dead wood substrates in young managed forest stands. The second aim is to test the effects of stand and local variables on occurrence probability and abundance of epixylic lichens and bryophytes. My questions are:

1) How large are the amounts of FWD (fine woody debris, diameter <10 cm) and CWD (coarse woody debris, diameter >10 cm) in these young forests?
2) How, if at all, do the qualities of the dead wood affect occurrence probability and abundance of epixylic lichens and bryophytes in young forests?
This study seeks to contribute with a part of the knowledge that is needed when evaluating stump harvest.

2 Methods

2.1 Study area

The study stands are located in the province of Uppland (59^{o}43´ N, 17^{o}30´ E) in southern mid-Sweden (Figure 2). The vegetation zone is hemiboreal (Ahti *et al.*, 1968), which is dominated by *Picea abies* (Norway spruce), followed by *Pinus sylvestris* (Scots pine) and deciduous trees (Fridman & Walheim, 2000). Annual precipitation for 1961-1990 was estimated to 600-700 mm and mean temperature was 5-6^{o}C (Raab & Vedin, 1995). The month with the highest mean temperature was July (16-18^{o}C) and the coldest month was January (-4- -6^{o}C).

2.2 Study stands and sampling

The chosen stands were dominated by *P. abies* before the recent final felling. There were two reasons for choosing *P. abies*. Firstly, spruce is together with pine dominating the Swedish forests (Fridman & Walheim 2000). Secondly, it is the tree species most economically attractive for stump harvest, since their stumps are easier to extract than pine stumps (Egnell *et al*., 2007).

The stands were 9-16 years old and at least 2 ha large. From these criteria, seven stands were chosen from the forest databases of Holmen Skog and Bergvik Skog AB. The seven stands and the visiting order were chosen randomly.

The stand maps were divided into square grids, and the intersections ("points") were numbered. The points to be visited were randomly selected. A GPS-receiver was used to find the points in the field. The point was excluded if it was situated within 25 m from the stand border or in non-passable wetland. Three points were visited in each stand. At each point I placed three plots. Each plot was 10 x 5 m and together they formed a triangle (Figure 3). The shape was chosen to avoid that linear elements, as ditches, have a bigger influence on the results than they should have.

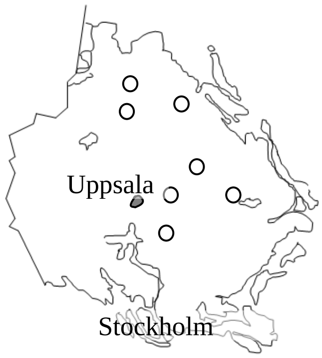

Figure 2. The stands are marked as circles in the map of Uppland.

2.3 Estimation of dead wood amounts

All CWD objects were investigated in all plots. For the first randomized point dead wood amounts of FWD with diameter over 1 cm were measured in plot 1, in the second point in plot 2 and in the last point in plot 3. A dead wood object was measured if some part of the object was visible. If an object was covered by ground-living bryophytes and being only humus it was not defined as a dead wood object. All stumps and snags with center inside the plot were measured. For the stumps, diameter and height were measured. For logs the diameter in both ends, respectively, and length were measured. If a log was situated with some part/s outside the plot, the diameters at the plot borders were measured. This was done to be able to calculate the amount of dead wood. For the snags the bottom diameter was measured and the height and the top diameter were estimated.

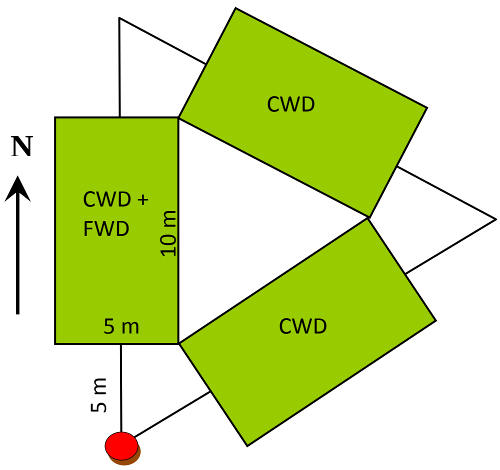

Figure 3. The inventoried plots (modified after Salomonsson 2010). In three triangles per stand estimations of dead wood and species registrations were done.

At high FWD-amounts of at least 10 objects in a few squaremetres, every fifth object was measured for environmental and substrate variables and the rest only for species.

The results of estimations and measurements were applied to the rest of the FWD. When five objects were measured the rest of the objects were counted.

I calculated the total volume for each dead wood object and the volume of the part of the object that was inside the plot. Area of stumps, snags, logs and slash were calculated, both the area of the part of the object that was inside the plot and the whole area of the objects. I only used 2/3 of the area of the logs and slash, since I assumed that lichens and bryophytes can only use the upper parts and the sides of the objects. Area without bark was also calculated, by subtracting the bark coverage from the area of the object.

2.4 Explanatory variables

For all dead wood objects I noted decay class, shade, humidity and bark coverage. The exception was at large FWD-amounts, where explanatory variables were only estimated for every fifth object. Decay classification (Table 3) is modified after Hottola & Siitonen (2008). Shade was estimated at a scale from 1 to 3 where 1 represented sun exposed the main part of the day and 3 represented shaded the main part of the day. The bark coverage was noted as percent of the original bark coverage of the object. Humidity was estimated at a scale from 1-4, according to a modification of the Swedish National Forest Inventory (Table 4).

Table 3. The five different decay classes, modified after Hottola & Siitonen (2008). A knife was used when estimating the decay classes.

Decay class	**1**	**2**	**3**	**4**	**5**
Definition	Hard	Relatively hard	Relatively soft	Soft throughout	Very soft
Grade of knife penetration	A few mm	1-2 cm	2-5 cm	The whole steel penetrates	The wood falls apart

Table 4. Humidity classification, modified from the Swedish National Forest Inventory.

Humidity class	**1**	**2**	**3**	**4**
Description	Dry ground, groundwater surface deeper than 2 m	Mesic ground, groundwater surface at 1-2 m.	Moist ground, groundwater surface at less depth than 1 m and in most cases visible in hollows.	Wet ground, groundwater forms bodies of water at the soil surface.

2.5 Species registrations

I noted occurrence of the focal lichen and bryophyte species on all dead wood objects in the plots. The exception was at large FWD-amounts, where species registrations were done for every fifth object, and not as thorough for the rest. The lichen species were *Calicium glaucellum, C. trabinellum, Cladonia botrytes, C. parasitica, Hypocenomyce sorophora, Mycocalicium subtile, Xylographa parallela* and *X. vitiligo.* The bryophyte species were *Anastrophyllum hellerianum, Buxbaumia viridis, Lophocolea heterophylla, Herzogiella seligeri and Nowellia curvifolia*. Nomenclature follows Santesson *et al.* (2004) for lichens and Hallingbäck *et al.* (2006) for bryophytes. All of the study species have dead wood as main substrate (Tibell &Wedin, 2000; Hallingbäck, 1995; 1996). Some of the species are common and some are uncommon.

When identification problems arose the specimens were collected and studied in a stereo magnifier.

2.6 Statistics

2.6.1 Dead wood analyses

Paired t-tests in Minitab® 15.1.1.0. were used to test differences in number, volume and area between FWD and CWD. Data were tested for normal distribution using the Anderson-Darling test. The number of dead wood objects was not normally distributed and therefore it was analyzed with the non-parametric Wilcoxon test, comparing the median values.

2.6.2 Species analyses

For the species with a sufficient number of occurrences I tested which variables that had significant effects on species occurrence. Since the data was binomially distributed, logistic regression was used, with the logit link function. Generalized Linear Models (Proc Genmod) in the program SAS was used. To relieve the effect of order in which the terms for the model were specified a type 3 analysis was used. There was high correlation (Pearson coefficient >0.6) between area and volume, and between area and area without bark. Volume and area without bark was excluded from the analyzes, because area was assumed to affect the occurrence to a higher extent. Following explanatory variables were tested: humidity, decay class, area of the dead wood objects, shade, object size (FWD/CWD) and log/stump. First every variable was analyzed separately. Models were built with the variables that had a p-value below 0.2. One by one the least significant variables were excluded until variables with $p < 0.1$ remained.

3 Results

3.1 Dead wood amounts

The median number of dead wood objects/ha was higher for FWD than CWD (Table 5). Mean value for the area was also higher for FWD than CWD, while mean of volume/ha was lower for FWD than CWD.

Table 5. Amounts of observed CWD and FWD. For number of objects medians are shown and in parenthesis the confidence intervals (at 94.8 level). The p-values are derived from the Wilcoxon test. Volume and area means are shown and the standard errors of the means. The p-values are derived from paired t-tests.

	CWD	FWD	p-value
Objects (no./ha)	667 (444, 911)	8233 (5467, 16567)	Not determined
Volume (m^3/ha)	25.15 ± 6.09	6.63 ± 1.06	0.015
Area (m^2/ha)	355 ± 62	580 ± 111	0.029

The distributions of the different investigated dead wood types are shown in Table 6. The number of objects/ha was highest for slash and second highest for FWD-stumps. The area of dead wood per ha was largest for slash and second largest for logs. However, area per ha of stumps was almost as large as for logs. Logs and CWD-stumps had the largest volume per hectare, 12.7 m^3/ha and 12.1 m^3/ha respectively.

Table 6. Dead wood amounts of different types of dead wood and the sum of all types are shown. The table shows the number, volume and area means and the standard error of the means. The percentage of the whole amount of dead wood is also shown.

	N.o. objects		**Surface area**		**Volume**	
	Objects/ha	Percent	m^2/ha	Percent	m^3/ha	Percent
CWD-stumps	397 ± 62.4	3.8	162 ± 25.2	17.3	12.1 ± 2.20	38.1
CWD-logs	257 ± 35.9	2.4	181 ± 47.4	19.4	12.7± 4.9	39.8
CWD-snags	6.35 ± 4.10	0.1	12.2 ± 7.88	1.3	0.4 ± 0.252	1.2
FWD-stumps	1010 ± 366	9.6	22.3 ± 7.56	2.4	0.20 ± 0.067	0.6
Slash	8790 ± 2724	83.7	555 ± 111	59.4	6.42 ± 1.05	20.2
FWD-snags	38.1 ± 13.5	0.4	2.0 ± 1.35	0.2	0.01 ± 0.0093	0.0004
Total	10498 ± 2988	100	935 ± 160	100	31.8 ± 6.49	100

3.2 Species occurrence

Of the 13 focal species five species were found: *C. glaucellum, C. botrytes, M. subtile, X. parallela* and *L. heterophylla*. Of these, there were enough occurrences to allow for statistical testing of possible connections between occurrences of *C. botrytes, M. subtile* and *X. parallela* and substrate qualities.

There was a higher probability of occurrence of *X. parallela* on CWD, compared with FWD (Table 7). The occurrence probability of *C. botrytes* was higher on stumps compared to logs. No variable significantly affected the occurrence probability of *M. subtile*, although the occurrence was higher at CWD than FWD.

Table 7. Parameter estimates in generalized linear models for occurrence probability of X. parallela *and* C.botrytes. *The p-values, and standard errors of the mean are shown.*

	p-value	Estimate	Mean SE
X. parallela occurrence			
Intercept	<0.001	-5.19	0.16
CWD	0.08	2.02	0.38
FWD	0	0	"
C.botrytes occurrence			
Intercept	0.002	-1.77	0.57
Stumps	0.01	0.94	0.36
Logs	0	0	"

4 Discussion

FWD had the highest number of objects and largest area, while CWD had the highest volume. My study has shown that CWD and FWD in young managed forests are potential substrates for some epixylic lichens. Though for *C. botrytes* an *X. parallela* CWD is more important than FWD, since *C. botrytes* only was found on CWD and *X. parallela* was found to a greater extent at CWD.

4.1 Dead wood amounts

In this study a higher number of FWD- than CWD- objects was found. By definition CWD-objects have larger diameter than FWD-objects; hence the volume per hectare can be larger than that of FWD even if there are more FWD-objects. Small objects have a larger area compared to the volume, than large objects, so the larger area of slash in young forests seems reasonable. Concerning proportion of number of objects and volume distribution between CWD and FWD, there are two studies that follow the same pattern as my study. Thinned forests and woodland key habitats (WKHs) in Uppland were studied by Salomonsson (2010). Managed forests in the county of Västernorrland, representing different the stand ages present in the landscape, were studied by Kruys & Jonsson (1999). All of these studied forests were dominated by Norway spruce. The difference between the study by Kruys & Jonsson (1999) and my study in distribution among dead wood types is that in managed forests in the county of Västernorrland there was a larger surface area of CWD than FWD. The difference may be that the young forests contain much slash, which may not be the case in managed forests in general. Though, Kruys and Jonsson (1999) did not investigate stumps, only logs. In addition, the included FWD was 5-9 cm in diameter, while in the other studied the smallest diameter was 1 cm.

The volume of dead wood in the present study was much higher than the average volume of dead wood in Swedish managed forests (7.6 m^3/ha) (Swedish Forest Agency, 2009). However, the lower values of the total volume of dead wood can be caused by stumps not being included in the estimations (Egnell, 2007:40). The volume of CWD-stumps in this study was 12.1 m^3 compared to 24 m^3/ha in another study in young managed forests in Sweden (Caruso *et al.*, 2008). They also show that only 25-30% of the stump volume was left after 18 years, i.e. 6-8 m^3/ha. The volume of stumps in my study was thus in between the two before mentioned amounts.

There were few snags, compared to the other dead wood types. The same pattern was found by in young managed forests by Sturtevant *et al*. (1997) and Duvall & Grigal (1999).

4.2 Species occurrence

That there was a higher probability for occurrence of *C. botrytes* on CWD than on FWD is in accordance with Caruso *et al*. (2008) and Kruys & Jonsson (1999). However in both mentioned studies *C. botrytes* was found also on FWD. The reasons for CWD suiting lichens better than FWD can be the larger surface area (a direct effect of the larger diameter) (Kruys & Jonsson 1999) and that it takes longer time for larger logs to get overgrown by ground vegetation (Söderström 1988b). This may lead to a higher probability for the substrate to be colonized by epixylic species (Söderström, 1988b). The influence of the area size has been observed earlier in other studies. E.g. Kruys *et al*. (1999) indicate that larger diameter CWD tend to have a higher occurrence of cryptogam species. The higher occurrence of *C. botrytes* on stumps than on logs is consistent with the description of Santesson *et al*. (2004), who states that it often occurs on the cut surface of stumps. Concerning the higher occurrence of *X. parallela* on CWD than FWD, it could be the same explanation as for *C. botrytes*. The highest number of observations was done of *C. botrytes*, which is a common species (Hallingbäck 1995).

The fact that I found a higher number of lichen than bryophyte species, and higher occurrence for each species could be explained by many lichens´ relatively good capacities to withstand small water amounts (Hallingbäck 1995). Bryophyte richness is favored by a damp and stable climate (Söderström 1983). Therefore, finding few bryophyte species and low occurrence was expected, because managed forests more often have periods of drought (Söderström 1988a). However Caruso & Rudolphi (2009) also found *H. seligeri* in young forests, but in low frequencies and only in the stands 16-18 years old. Like in this study, Caruso & Rudolphi registered *L. heterophylla* in low frequencies. In another study, Rudolphi *et al*. (unpublished data) studied old-growth bryophytes and lichens in young (30-70 years old) forests in Gävleborg County. They found the red-listed species *A. hellerianum* and *C. parasitica*, which were not registered in the present study. Söderström (1988a) finds that liverworts living on dead wood occurred more frequently in natural than managed stands. In the same study it is found that species of *Cladonia* occurred more often in a managed that an unmanaged stand. The managed was more often dry, which may explain the result of the two groups (Söderström 1988a). These findings may also explain my results.

The small number of snags sampled may have resulted in the snags in this study not being representative for the whole investigated area. In another study a greater number of snags were investigated; 20 without bark and 22 with bark compared to 2 CWD-snags in total in my study (Lõhmus & Lõhmus, 2001). They found *M. subtile* on 70 % of the *P. abies* snags without bark and *C. glaucellum* on 20 % of the *P. abies* snags without bark.

4.3 Improvements and further studies

Other studies in the same subject area could be done. For example it would be interesting to compare stands where stump harvest has been practiced and stands with stumps left. In such a study it may be observed whether or not stump harvest is affecting occurrence of lichens on other dead wood substrates. This may show one effect of the result of stump harvest concerning epixylic lichens.

It would be interesting to study which types of stands that could be stump harvested with the least negative impact for lichens and bryophytes. This may be done by analyzing how important stumps are in relation to other substrates for lichens and bryophytes in the different stand types. E.g. stands with different tree species could be compared.

4.4 Conclusions

One conclusion is that in the estimations of dead wood, stumps should be included. Promoting increasing stump harvest and at the same time increase of the dead wood is contradictory.

From a perspective of *C. botrytes*, CWD-stumps are important substrates. Hence, it could be one argument for not practicing stump harvesting. From the occurrence distribution of *X. parallela* it is possible to say that it is important to save CWD at final felling, logs and stumps being equally important. Since even FWD hosts some epixylic lichen species, also slash harvest is negative for them. However, if choosing between stumps and slash harvest, this study suggests that stump harvest gives the most negative effects on *C. botrytes*. One advice of the Swedish Forest Agency to the Swedish Forestry Act is to leave old windfalls, high stumps and snags at final felling (SKSFS 1993:2). This seems important, but I think that stumps also should be saved.

The results of this study suggest that although stump removal may be economically beneficial, at least some stumps should be saved because they are important for *C. botrytes* and to a certain degree for *X. parallela*. However, when evaluating stump harvest there are many other aspects to take into account. Some aspects could be occurrence and richness of other species, and forest productivity.

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Appendices

Appendix 1. Sum of number of dead wood objects of the different sizes and types.

Size or type of wood	number of objects
FWD	1033
CWD	208
FWD-stumps	106
Slash	923
FWD-snags	4
CWD-stumps	125
Logs	81
CWD-snags	2
total	1241

Appendix 2. Sum of number of dead wood objects with occurrence of the focal bryophyte and lichen species.

Size or type of wood	*C. botrytes*	*X. parallela*	*M. subtile*	*C. glaucellum*	*L. heterophylla*
FWD	0	5	1	0	1
CWD	52	8	14	2	1
FWD-stumps	0	0	1	0	0
Slash	0	5	0	0	1
FWD-snags	0	0	0	0	0
CWD-stumps	41	4	10	1	1
Logs	11	4	4	1	0
CWD-snags	0	0	0	0	0
total	52	13	15	2	2

Appendix 3. Percent of the observed dead wood objects with occurrence of the bryophyte and lichen species in the plots.

	C. botrytes	**X. parallela**	**M. subtile**	**C. glaucellum**	**L. heterophylla**
FWD	0	0.48	0.097	0	0.097
CWD	25.2	3.9	6.8	1.0	0.49
FWD-stumps	0	0	0.94	0	0
Slash	0	0.5	0	0	0.11
FWD-snags	0	0	0	0	0
CWD-stumps	32.8	3.2	8	0.8	0.8
Logs	13.9	5.1	5.06	1.3	0
CWD-snags	0	0	0	0	0
total	4.2	1.05	1.21	0.16	0.161

Appendix 4. Total area of the bryophyte and lichen species in the plots.

Size or type of wood	**C. botrytes (cm^2)**	**X. parallela (cm^2)**	**M. subtile (cm^2)**	**C. glaucellum (cm^2)**	**L. heterophylla (cm^2)**
FWD	0	31	156	0	4
CWD	2338.5	307	1423	3792	4
FWD-stumps	0	0	156	0	0
Slash	0	31	0	0	4
FWD-snags	0	0	0	0	0
CWD-stumps	2099	260	579	8	4
Logs	239.5	47	844	3784	0
CWD-snags	0	0	0	0	0
total	2338.5	338	1579	3792	8

Appendix 5. Mean area of the species per dead wood object.

	C. botrytes (cm^2)	**X. parallela (cm^2)**	**M. subtile (cm^2)**	**C. glaucellum (cm^2)**	**L. heterophylla (cm^2)**
FWD	0	0.030±0.014	0.15± 0.15	0	0.0039± 0.0039
CWD	11.4± 4.30	1.49±1.01	6.91±2.83	18.4±18.4	0.019±0.019
FWD-stumps	0	0	1.47±1.47	0	0
Slash	0	0.034±0.016	0	0	0.0043±0.0043
FWD-snags	0	0	0	0	0
CWD-stumps	16.8±6.97	2.08±1.65	4.63±2.40	0.064±0.064	0.032±0.032
Logs	3.03±1.79	0.60±0.33	10.7±6.33	47.9± 47.9	0
CWD-snags	0	0	0	0	0
total	1.89±	0.27±	1.27±	3.06±	0.0065±